LOAN DOCUMENT

PHOTOGRAPH THIS SHEET

LEVEL

0

INVENTORY

DTIC ACCESSION NUMBER

RIA-80-U768

DOCUMENT IDENTIFICATION

JUN 80

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR
NTIS GRA&I
DTIC TRAC
UNANNOUNCED
JUSTIFICATION

BY
DISTRIBUTION/
AVAILABILITY CODES

DISTRIBUTION	AVAILABILITY AND/OR SPECIAL	
A-1		

DISTRIBUTION STAMP

DATE ACCESSIONED

DATE RETURNED

19990517069

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NUMBER

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

HANDLE WITH CARE

DTIC FORM 70A JUN 90

DOCUMENT PROCESSING SHEET

PREVIOUS EDITIONS MAY BE USED UNTIL STOCK IS EXHAUSTED.

LOAN DOCUMENT

TECHNICAL REPORT ARLCB-TR-80023

LASER TREATMENT OF CHROMIUM PLATED STEEL

R. S. Montgomery

June 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

AMCMS No. 611102H6002

DA Project No. 1L161102H60

PRON No. 1A9243241A1A

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ARLCB-TR-80023
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): LASER TREATMENT OF CHROMIUM PLATED STEEL
5. TYPE OF REPORT & PERIOD COVERED
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): R. S. Montgomery
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Armament Research and Development Command, Benet Weapons Laboratory, DRDAR-LCB-TL, Watervliet, N. Y. 12189
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AMCMS No. 611102H6002, DA Project No. 1L1161102H60, PRON No. 1A9243241A1A
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Armament Research and Development Command, Large Caliber Weapon Systems Laboratory, Dover, New Jersey 07801
12. REPORT DATE: June 1980
13. NUMBER OF PAGES: 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES: Presented at the 4th International Tribology Conference, Paisley, 10-15 September 1979. Published in technical journal Wear, Volume 56, 1979, pages 155-166.
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Electroplating
Chromium
Wear
Heat Affected Zone
Laser Treatment
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Both flat steel coupons and rolls for a geared-roller test machine were chromium plated and laser treated in an effort to improve adhesion. Under the experimental conditions the electroplate was rendered considerably softer but more fragile. A Cr-Fe alloy was produced at the interface at the slower processing speeds and the steel under the electroplate was considerably hardened by the formation of untempered martensite. While this work shows only much decreased durability for laser-treated chrome plate, perhaps other experimental conditions might show improved properties.

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

Wear, 56 (1979) 155 - 166

LASER TREATMENT OF CHROMIUM PLATED STEEL*

R. S. MONTGOMERY

U.S. Army Armament Research and Development Command, Benet Weapons Laboratory, Watervliet Arsenal, Watervliet, N.Y. 12189 (U.S.A.)

(Received March 27, 1979)

Summary

Both flat steel coupons and rolls for a geared-roller test machine were chromium plated and laser treated in an effort to improve adhesion. Under the experimental conditions the electroplate was rendered considerably softer but more fragile. A Cr–Fe alloy was produced at the interface at the slower processing speeds and the steel under the electroplate was considerably hardened by the formation of untempered martensite. While this work shows only much decreased durability for laser-treated chrome plate, perhaps other experimental conditions might show improved properties.

1. Introduction

The bores of many cannon tubes are electroplated with chromium to provide better resistance to erosion and wear and in the case of naval guns to provide corrosion resistance. The erosion resistance of chrome plate is probably related to its high melting point; its initial hardness near the origin of rifling where most of the erosion takes place is of secondary importance. In any case the hardness of the chromium in this region rapidly falls owing to the temperatures produced during firing. Down the tube, where wear is by sliding of the projectile on the cannon bore [1], hardness of the chrome plate is probably desirable. Erosion resistance of chrome plate is very good; there is virtually no erosion until the chromium begins to spall off the steel substrate.

If the resistance to spalling of chrome plate could be increased, its durability on a cannon bore would be improved. It was felt that laser treatment of the electroplate could improve its adhesion to the substrate steel by producing an intermediate layer of intermediate properties. Improvement of adhesion of chrome plate to steel was attempted by Brenner *et al.* [2] by heat treatment but the results were disappointing presumably because of the

---

*Paper presented at the 4th International Tribology Conference, Paisley, Sept. 10 - 15, 1979.

brittle character of the intermediate Cr–Fe alloy. However, laser treatment of the electroplate could be different because of the extremely rapid heating and quenching. It is well known that laser treatment of steel produces a hard case [3] and a harder substrate should improve the spalling resistance of the electroplate. A peculiar advantage of laser treatment is that the origin of rifling could easily be treated without affecting the hard chrome on the remainder of the bore.

2. Experiments using flat plates

Flat specimens of AISI 4340 steel were heat treated so that the microstructure would be entirely tempered martensite as it is with cannon tubes and they were then plated with chromium to thicknesses ranging from 1 to 10 mil. The specimens measured were 4 in × 4 in square and 0.5 in thick. It was felt that specimens of this size were desirable to eliminate or at least minimize boundary effects during laser treatment. The laser used was a 15 kW industrial system which was a continuous wave closed-cycle CO_2 device producing 10.6 μm laser radiation. It was completely water cooled and capable of continuous operation. The optical package for surface treatment was mounted on top of the work station. Typically it contains an $f/150$ telescope, scanning optics and several directing mirrors. The beam was focused for scanning across the workpiece with a rectangular area of variable size and aspect ratio. Two of the mirrors in the optical system were electrodynamically driven in mutually perpendicular directions at frequencies high enough to approximate a continuous wave beam. The oscillating beam was then passed through an aperture to define the limits of the electrodynamically induced motion. The amplitude of the oscillation and the dimensions of the aperture were all independently adjustable so that both the overall size and the aspect ratio of the treated zone of the workpiece could be varied at will. No special fixture was used for the treatment of the flat coupons.

The thicknesses of the electroplates were in groups of nominally 1, 2, 5 and 10 mils. The power of the laser beam was 7.5 kW in all cases and the speed of travel of the beam across the specimen ranged from 15 to 40 in min^{-1}. Flat black spray paint was used as an energy-absorbing coating and helium was used as a protective gas blanket. While the results varied from specimen to specimen depending on the plate thickness and the processing conditions, essentially the same effects were observed in all experiments.

3. Results of laser treatment

(1) The electroplate did not melt but it was rendered considerably softer. Before treatment it had a hardness of 920 - 1140 KHN. After laser treatment, the hardness of the electroplate varied with distance from the center of the laser traverse and usually varied through the plate with the

chromium near the surface being softer. Hardnesses ranged from 150 to 280 KHN with a value of 250 KHN being typical (see Fig. 1).

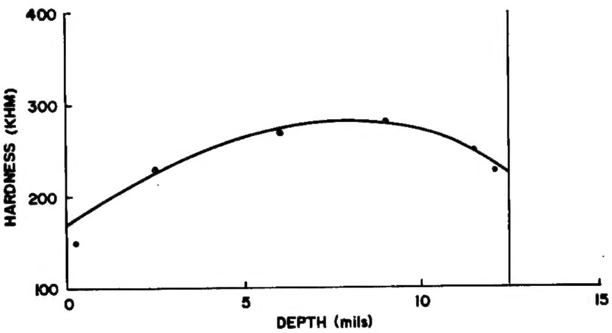

Fig. 1. Hardness of chrome plate after laser treatment (7.5 kW, 40 in min^{-1}, 12.5 mil plate).

Softening of chrome electroplates on heat treatment is well known. Snavely and Faust [4] found that an electroplate with a hardness of almost 1000 KHN was softened to 210 - 240 KHN on heating for 12 h at 700 °C. There was a minor decrease in hardness at 300 °C presumably due to stress relief but a rapid decrease in hardness on heating over 500 °C which the authors ascribed to recrystallization and grain growth in the plate. After laser treatment the electroplates showed grain growth but also showed agglomeration of inclusions which had been too small to be seen in the original electroplates. Apparently there had been agglomeration of the oxide constituent which according to Sully and Brandes [5] also contributes to softening.

(2) The microcracks present in the original electroplates were eliminated by laser treatment and the residual stresses were nil as measured by X-ray diffraction. However, there were macrocracks on some of the specimens. Usually they appeared unimportant but at least one specimen showed a whole network of cracks. There was no correlation apparent between the presence of cracks and the processing speed although the specimens treated at 20 in min^{-1} always showed cracks at both ends of the laser traverses.

(3) An intermediate layer of intermediate hardness (about 350 KHN) was produced between the steel and the chromium. Figures 2 and 3 show that it had been molten. At a power of 7.5 kW and a processing speed of 40 in min^{-1} hardly any intermediate layer was produced while a processing speed of 20 in min^{-1} caused the formation of an intermediate layer 0.6 - 1.1 mil thick with the thinner plates having the thicker intermediate layers (see Fig. 4). There were sometimes small surface lumps of this material at both ends of the laser traverses on the specimens treated at 20 in min^{-1}. The intermediate layer was an alloy of chromium and iron as determined by electron microprobe studies (see Fig. 5). Its composition varied from 35 ± 5 wt.% chromium at the steel side of the layer to 45 ± 5 wt.% chromium at the chromium side. Although the high chromium side of the layer could be FeCr based on composition, the sluggish nature of the reaction which forms FeCr

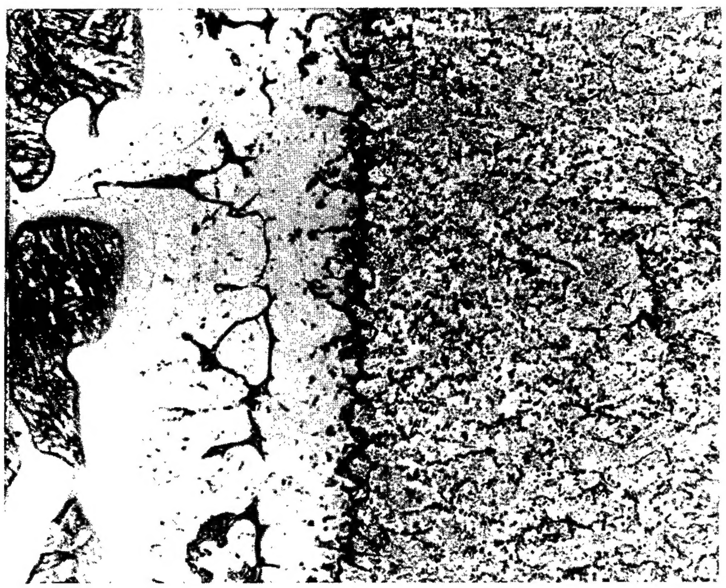

Fig. 2. Intermediate layer between steel and chromium (magnification 400×).

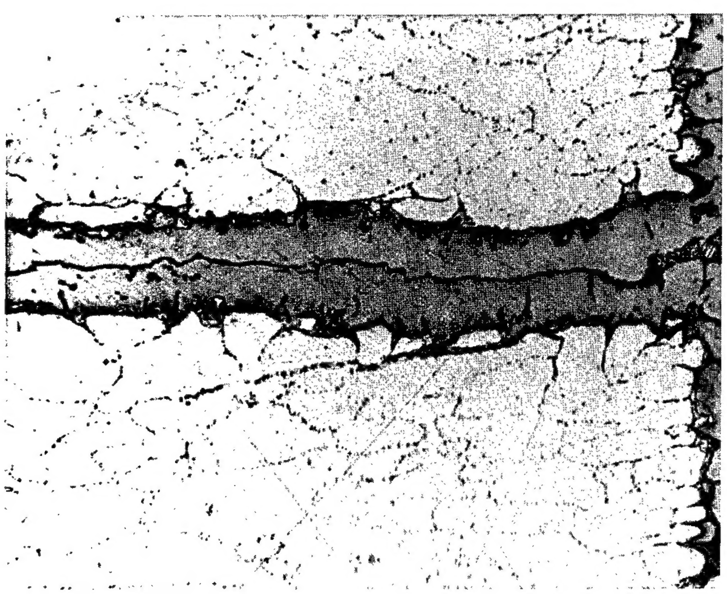

Fig. 3. Cross section of a laser-treated chrome plate showing the intermediate layer welling to the surface through a crack (magnification 400×).

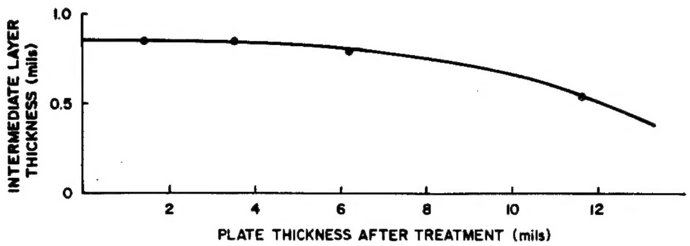

Fig. 4. Intermediate layer thickness as a function of plate thickness (7.5 kW, 19.5 and 22.0 in min^{-1}).

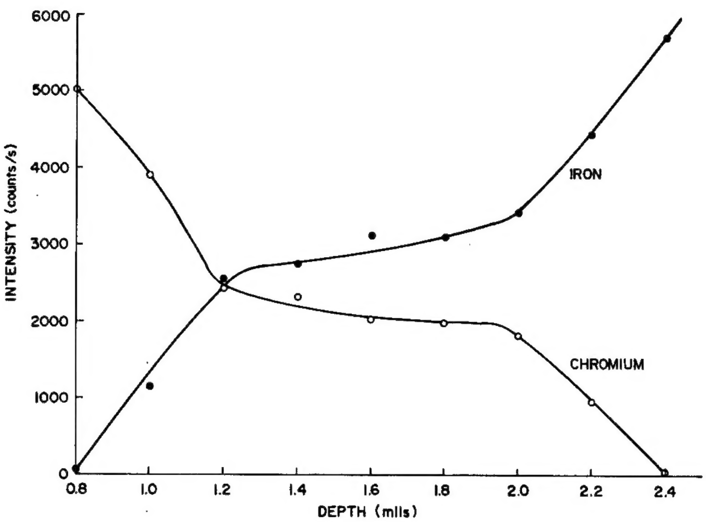

Fig. 5. X-ray intensities characteristic of iron and chromium through intermediate layer (7.5 kW, 22 in min^{-1}, 1.0 mil plate).

[6] suggests that the compound would not form during the rapid quench associated with laser treatment. In any case the intermediate layer showed no tendency to crack at hardness impression loads which caused severe cracking of the chrome plate. Therefore it was not excessively brittle. There were also islands of another phase which appeared to be chromium carbide in the intermediate layer (see Fig. 6). Scanning Auger spectroscopy indicated that there was an appreciable amount of carbon present as carbide in the intermediate layer especially at the interface between the chromium and the intermediate layer so it seems likely that this identification is indeed correct.

(4) The substrate steel under the electroplate was considerably hardened (see Fig. 7). Before laser treatment, it was entirely tempered martensite with a hardness of 390 - 400 KHN. The steel hardness directly below the chromium in this specimen was about 530 KHN and it became progressively harder reaching a maximum of about 680 KHN before falling

Fig. 6. Islands of another phase in intermediate layer (magnification 800×).

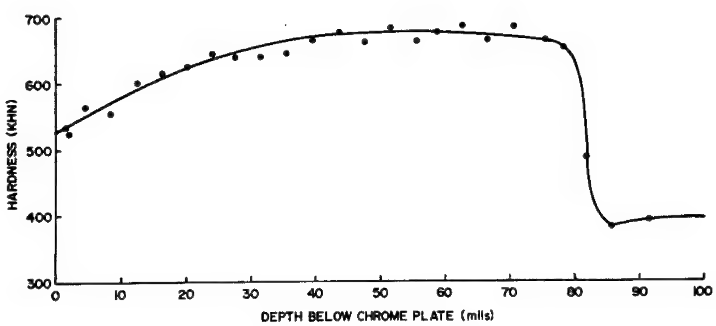

Fig. 7. Hardness of laser-treated steel as a function of depth (7.5 kW, 40 in min^{-1}, 10 mil plate).

abruptly to its original value. This specimen had been processed at 7.5 kW and 40 in min^{-1} but it is typical of the others. A slower processing speed produced deeper hardening. The grains immediately below the chromium were large and easily identified as untempered martensite (see Fig. 8). Below this the grains were too small for their morphology to be identified (see Fig. 9). However, they are possibly also untempered martensite. To verify this a specimen of laser-hardened steel (not chrome plated) was tempered for 2 h at 650 °C in a vacuum. After this tempering the hardness of the steel returned to its original value allowing for the small grain size of some of its structure (see Fig. 10).

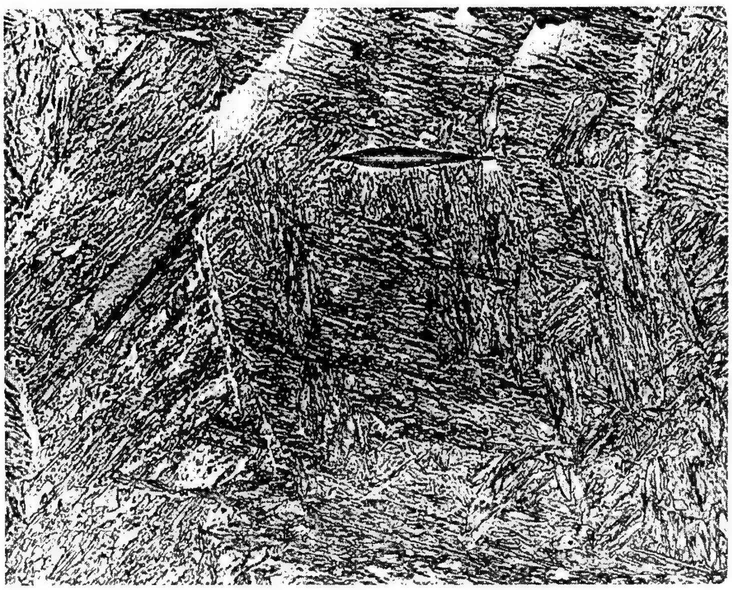

Fig. 8. Steel structure immediately below the chromium showing untempered martensite (magnification 400×).

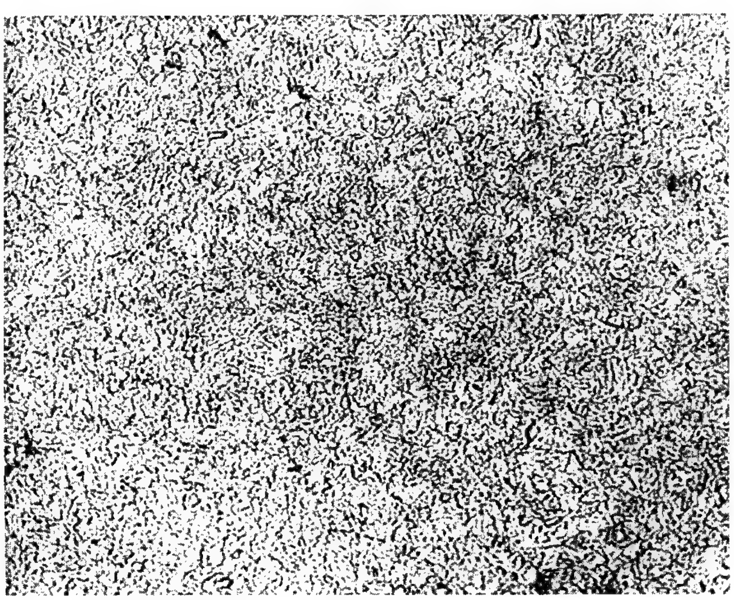

Fig. 9. Steel structure below the untempered martensite showing small grains (magnification 400×).

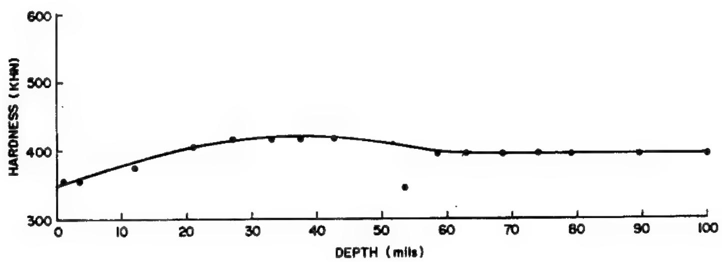

Fig. 10. Hardness of laser-treated steel after annealing as a function of depth (7.5 kW, 40 in min^{-1}).

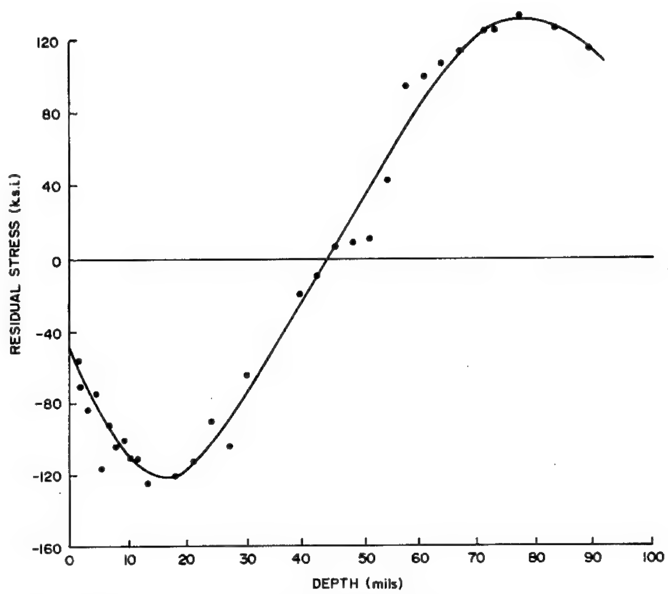

Fig. 11. Residual stress as a function of depth in laser-treated steel (7.5 kW, 40 in min^{-1}).

(5) Laser treatment caused residual compressive stresses in the substrate steel (see Fig. 11). The stresses were measured using the X-ray diffraction method on an unplated laser-treated steel specimen. Similar results would be expected on a plated specimen.

4. Experiments using a geared-roller test machine

Laser-treated chromium plated rollers were tested using a geared-roller test machine (Caterpillar Corporation) operated with oil lubrication under conditions of nominally pure rolling. It was felt that these conditions would adequately simulate the melt-lubricated sliding of a projectile down a cannon bore where the coefficient of friction is about 0.02 [7] without the thermal

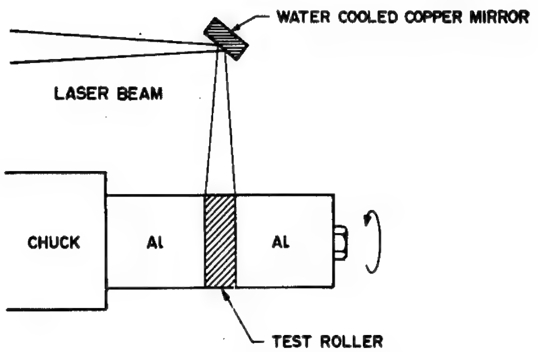

Fig. 12. Assembly used for laser treating test rollers.

effects present in an actual cannon. The velocity of rolling was 820 in s^{-1} which was the highest that could be conveniently obtained with a standard machine (5250 rev min^{-1}). A load of 4066 lbf was used on the test machine; this load was selected, not because it simulates any load in an actual cannon, but because it usually resulted in failure of the electroplate in a convenient length of time. The oil temperature was maintained between 46 and 68 °C so that its viscosity would be low but there would be no changes in the substrate or electroplate attributable to high temperature. These are the same conditions as were used in an earlier study of factors influencing the durability of chrome plate [8].

The test rollers were machined from gun steel (modified AISI 4330) and plated with chromium to thicknesses which ranged from 3.5 to 11.25 mil by means of the conventional procedure used on cannon bores. They were laser treated using a special rotary fixture in which the test roller was clamped between two aluminum blocks which acted as heat sinks. The complete assembly was centered in a chuck and rotated at an angular speed to produce the desired linear processing speed on the surface of the roll. The assembly is shown in Fig. 12. Almost all the rollers were laser treated at 7.5 kW and processing speeds of 20 or 40 in min^{-1}. However, two were treated at 14 kW, one of which was processed at 40 in min^{-1} and the other at 50 in min^{-1}. The length of the beam spot was kept constant at 0.7 in but the width was adjusted to cover the whole width of the ring. Again flat black spray paint was used as an energy-absorbing coating and helium was used as a protective gas blanket.

The two rollers treated at 14 kW showed large lumps of metal on the chrome surfaces (see Fig. 13). Metallographic studies showed them to be the Cr–Fe alloy which had welled up to the surfaces through cracks in the electroplate (see Fig. 3). Apparently the formation of the Cr–Fe alloy is associated with an expansion. Some of the rollers treated at 7.5 kW showed the same kind of metallic lumps but they were much smaller. These lumps were toward the side and not in the region of contact of the crowned rollers. Test rollers with surface lumps could not be tested with the geared-roller test machine unless the lumps were small enough to be stoned off.

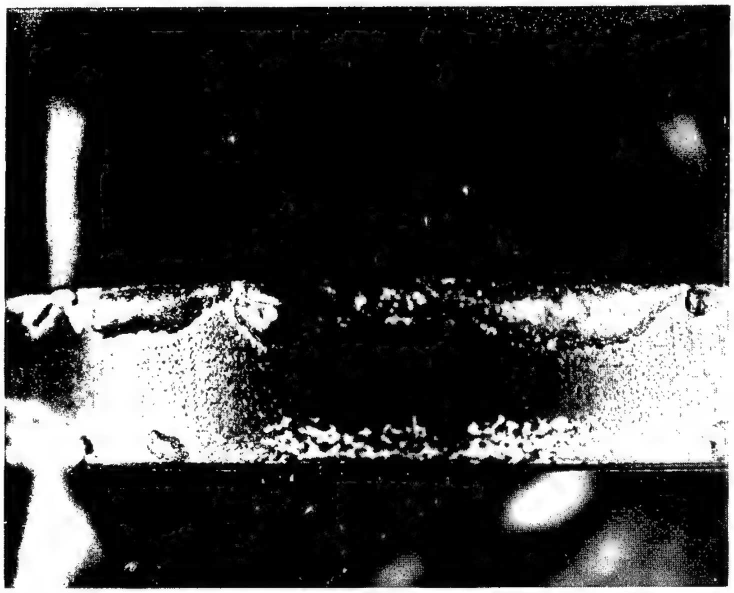

Fig. 13. Surface of a test roller treated at 14 kW showing large lumps of metal. The rollers were 0.5 in wide and had a diameter of 3.0 in.

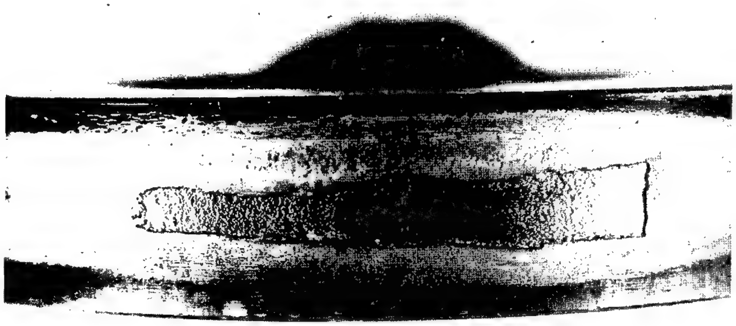

Fig. 14. Surface of a laser-treated roller after testing showing peeling of chrome plate.

The laser-treated rollers ran only from 14 to 47 s before large sections of the chrome plate peeled away (see Fig. 14). The nine rollers treated at 40 in min^{-1} ran from 14 to 47 s with an average life of only 25 s. Four of the rollers treated at 20 in min^{-1} could be tested; they ran from 15 to 25 s with an

average life of only 19 s. A life of about 17 min would be expected for chrome plated specimens which had not been laser treated. The mode of failure was also very different; the usual failure in specimens which had not been laser treated was in the steel immediately below the chromium interface. The chrome plate itself showed great durability; *e.g.* when the plate was on carburized steel it showed no distress at all after testing for 200 min at these same conditions [8]. The laser-treated electroplate showed severe cracking and failure (see Fig. 15). This was unexpected in view of its lower hardness and the lack of residual stresses and microcracks. A possible explanation may be nitrogen embrittlement of the chromium during laser treatment. It had been blanketed with helium during processing but the blanketing might not have been sufficient. Snavely and Faust [4] found that the nitrogen reaction would take place if the temperature were sufficiently high even though the concentration of nitrogen was very low. Wain *et al.* [9, 10] showed the strong embrittling effect of nitrogen and Cairns and Grant [11] showed that the effect was much greater for water-quenched samples than for slowly cooled samples. Quenching would be very rapid for the laser-treated electroplates.

5. Discussion

While this work shows only much decreased durability for laser-treated chrome plate it cannot be concluded that there is no promise in this kind of processing. A better blanketing technique during processing could perhaps prevent the excessive fragility of the treated chromium. In addition if a beam of higher power and a faster processing speed were used, a more abrupt

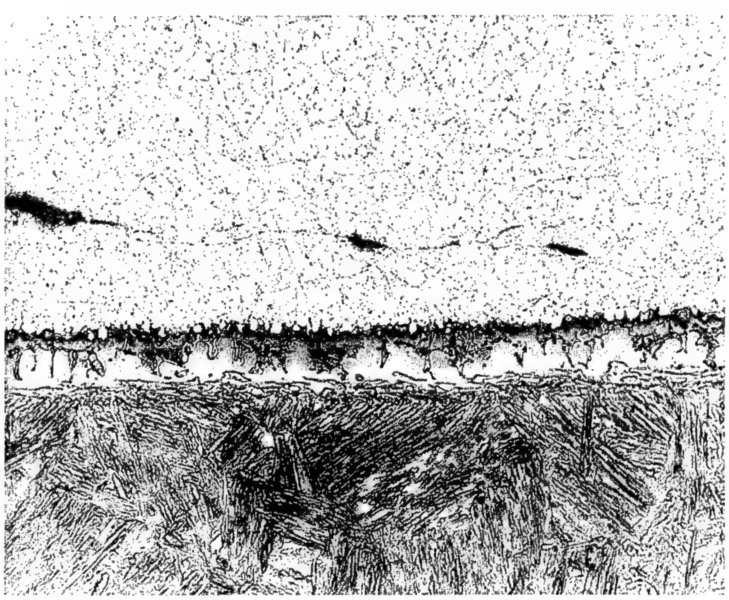

Fig. 15. Cross section of a laser-treated chrome plate after testing showing severe cracking (magnification 200×).

temperature profile through the plate would result and there would be little formation of the Cr–Fe alloy at the interface although there was no evidence from this work that formation of this alloy is deleterious except where so much is formed that it wells to the surface. There would also be less formation of untempered martensite in the substrate steel. It was felt that hardening and production of residual compressive stresses through formation of untempered martensite would probably not be beneficial; they would anneal away during firing, at least to a considerable depth. Again, the inherent brittleness of an untempered martensite structure might initiate excessive surface cracking during initial firing. With high power and fast processing the untempered martensite produced would be fine grained and probably not as brittle. Furthermore, under these conditions a chrome plate might be produced which would be softer, more stress free and perhaps more ductile and with greater durability in the origin-of-rifling region of a cannon.

Acknowledgments

The author would like to thank AVCO-Everett Research Laboratory for laser treating the specimens, Theresa Brassard for the metallography, William Baldauf for plating the rolls, George Capsimalis for the stress determination, Joseph Barranco for the annealing experiment, Joseph F. Cox for the electron probe analysis and Professor Peter Mark for the scanning Auger analysis.

References

1 R. S. Montgomery, Muzzle wear of cannon, *Wear, 33* (1975) 359 - 368.
2 A. Brenner, P. Burkhead and C. Jennings, Physical properties of electrodeposited chromium, *J. Res. Nat. Bur. Stand., 40* (1948) 31 - 59.
3 E. V. Locke, D. Gnanamuthu and R. A. Hella, High power lasers for metalworking, *Res. Rep. 398*, AVCO-Everett Research Laboratory, Everett, Mass., 1974.
4 C. A. Snavely and C. L. Faust, Studies on the structure of hard chromium plate, *Trans. Electrochem. Soc., 97* (1950) 99 - 108.
5 A. H. Sully and E. A. Brandes, *Chromium* (2nd edn.), Plenum Press, New York, 1967, p. 252.
6 A. H. Sully and E. A. Brandes, *Chromium* (2nd edn.), Plenum Press, New York, 1967, p. 316.
7 R. S. Montgomery, Surface melting of rotating bands, *Wear, 38* (1976) 235 - 243.
8 R. S. Montgomery and F. K. Sautter, Factors influencing the durability of chrome plate, *Int. Conf. on Wear of Materials, Dearborn, Michigan, April 1979.*
9 H. L. Wain, F. Henderson and S. T. M. Johnstone, A study of the room-temperature ductility of chromium, *J. Inst. Met., 83* (1954 - 55) 133 - 142.
10 H. L. Wain, F. Henderson, S. T. M. Johnstone and N. Louat, Further observations on the ductility of chromium, *J. Inst. Met., 86* (1957 - 58) 281 - 288.
11 R. E. Cairns and N. J. Grant, The effects of carbon, nitrogen, oxygen and sulfur on the ductile–brittle fracture temperature of chromium, *Trans. AIME, 230* (1964) 1150 - 1159.

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
COMMANDER	1
CHIEF, DEVELOPMENT ENGINEERING BRANCH	1
ATTN: DRDAR-LCB-DA	1
-DM	1
-DP	1
-DR	1
-DS	1
-DC	1
CHIEF, ENGINEERING SUPPORT BRANCH	1
ATTN: DRDAR-LCB-SE	1
-SA	1
CHIEF, RESEARCH BRANCH	2
ATTN: DRDAR-LCB-RA	1
-RC	1
-RM	1
-RP	1
CHIEF, LWC MORTAR SYS. OFC.	1
ATTN: DRDAR-LCB-M	1
CHIEF, IMP. 81MM MORTAR OFC.	1
ATTN: DRDAR-LCB-I	1
TECHNICAL LIBRARY ATTN: DRDAR-LCB-TL	5
TECHNICAL PUBLICATIONS & EDITING UNIT ATTN: DRDAR-LCB-TL	2
DIRECTOR, OPERATIONS DIRECTORATE	1
DIRECTOR, PROCUREMENT DIRECTORATE	1
DIRECTOR, PRODUCE ASSURANCE DIRECTORATE	1

NOTE: PLEASE NOTIFY ASSOC. DIRECTOR, BENET WEAPONS LABORATORY, ATTN: DRDAR-LCB-TL, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH & DEVELOPMENT ATTN: DEP FOR SCI & TECH THE PENTAGON WASHINGTON, D.C. 20315	1
COMMANDER US ARMY MAT DEV & READ. COMD ATTN: DRCDE 5001 EISENHOWER AVE ALEXANDRIA, VA 22333	1
COMMANDER US ARMY ARRADCOM ATTN: DRDAR-LC	1
-LCA (PLASTICS TECH EVAL CEN)	1
-LCE	1
-LCM	1
-LCS	1
-LCW	1
-TSS(STINFO) DOVER, NJ 07801	2
COMMANDER US ARMY ARRCOM ATTN: DRSAR-LEP-L ROCK ISLAND ARSENAL ROCK ISLAND, IL 61299	1
DIRECTOR US Army Ballistic Research Laboratory ATTN: DRDAR-TSB-S (STINFO) ABERDEEN PROVING GROUND, MD 21005	1
COMMANDER US ARMY ELECTRONICS COMD ATTN: TECH LIB FT MONMOUTH, NJ 07703	1
COMMANDER US ARMY MOBILITY EQUIP R&D COMD ATTN: TECH LIB FT BELVOIR, VA 22060	1
COMMANDER US ARMY TANK-AUTMV R&D COMD ATTN: TECH LIB - DRDTA-UL	1
MAT LAB - DRDTA-RK WARREN MICHIGAN 48090	1
COMMANDER US MILITARY ACADEMY ATTN: CHMN, MECH ENGR DEPT WEST POINT, NY 10996	1
COMMANDER REDSTONE ARSENAL ATTN: DRSMI-RB	2
-RRS	1
-RSM ALABAMA 35809	1
COMMANDER ROCK ISLAND ARSENAL ATTN: SARRI-ENM (MAT SCI DIV) ROCK ISLAND, IL 61202	1
COMMANDER HQ, US ARMY AVN SCH ATTN: OFC OF THE LIBRARIAN FT RUCKER, ALABAMA 36362	1
COMMANDER US ARMY FGN SCIENCE & TECH CEN ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER US ARMY MATERIALS & MECHANICS RESEARCH CENTER ATTN: TECH LIB - DRXMR-PL WATERTOWN, MASS 02172	2

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT)

	NO. OF COPIES
COMMANDER US ARMY RESEARCH OFFICE P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709	1
COMMANDER US ARMY HARRY DIAMOND LAB ATTN: TECH LIB 2800 POWDER MILL ROAD ADELPHIA, MD 20783	1
DIRECTOR US ARMY INDUSTRIAL BASE ENG ACT ATTN: DRXPE-MT ROCK ISLAND, IL 61201	1
CHIEF, MATERIALS BRANCH US ARMY R&S GROUP, EUR BOX 65, FPO N.Y. 09510	1
COMMANDER NAVAL SURFACE WEAPONS CEN ATTN: CHIEF, MAT SCIENCE DIV DAHLGREN, VA 22448	1
DIRECTOR US NAVAL RESEARCH LAB ATTN: DIR, MECH DIV CODE 26-27 (DOC LIB) WASHINGTON, D. C. 20375	1 1
NASA SCIENTIFIC & TECH INFO FAC P. O. BOX 8757, ATTN: ACQ BR BALTIMORE/WASHINGTON INTL AIRPORT MARYLAND 21240	1

	NO. OF COPIES
COMMANDER DEFENSE TECHNICAL INFO CENTER ATTN: DTIA-TCA CAMERON STATION ALEXANDRIA, VA 22314	12
METALS & CERAMICS INFO CEN BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
MECHANICAL PROPERTIES DATA CTR BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
MATERIEL SYSTEMS ANALYSIS ACTV ATTN: DRXSY-MP ABERDEEN PROVING GROUND MARYLAND 21005	1

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.